

Final Report

Title of project:

Basic Research for AOARD 104045 "Evaluation of laser oscillation properties
in polycrystalline ceramic slabs and waveguides, dated 4 Aug 09"

By

Dr. Tomosumi Kamimura

Osaka Institute of Technology,
5-16-1 Ohmiya, Asahi-ku, Osaka 535-8585, Japan

Submitted to

Asian Office of Aerospace Research & Development (AOARD)

7-23-17 Roppongi

Minato-ku, Tokyo 106-0032

TEL:(03)-5410-4409 FAX:(03)-5410-4407

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 12 AUG 2011		2. REPORT TYPE		3. DATES COVERED	
4. TITLE AND SUBTITLE Evaluation of laser oscillation properties in polycrystalline ceramic slabs and waveguides.				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Tomosumi Kamimura				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Electronics, Osaka Institute of Technology, 5-16-1 Ohmiya, Asahi-ku, Osaka, Japan, NA, NA				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The laser characteristics of slab/composite and waveguide ceramic sample developed and provided by Dr. Ikesue of World Laboratory Co., Ltd. were evaluated. Four kinds of three layer composite ceramic slab (Pure-0.6 or 1.0at%Nd-Pure, and Gd-0.6 or 1.0at%Nd-Gd) were prepared for this experiment. At the end-pumping laser oscillation, approximately 50% of slope efficiency was achieved in all samples.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

1. **ABSTRACT:** The laser characteristics of slab/composite and waveguide ceramic sample developed and provided by Dr. Ikesue of World Laboratory Co., Ltd. were evaluated. Four kinds of three layer composite ceramic slab (See Figure 1: Pure-0.6 or 1.0at%Nd-Pure, and Gd-0.6 or 1.0at%Nd-Gd) were prepared for this project. At the end-pumping laser oscillation, approximately 50% of slope efficiency was achieved in all samples. In the pure-0.6at%Nd, laser output of 69W was obtained at input power of 150W. However, a sample broke by thermal saturation due the strong pumping density

2. **INTRODUCTION**

Ceramic technology can provide microstructure and macrostructure in combination with innovative and novel system configuration of the ceramic gain media. We must focus on these advantages of ceramics to develop novel technologies which cannot be realized in single crystal materials. The ceramic laser gain media to be fabricated is controllable in macro-, micro- and nano-structural level, and generation of high-power laser from a small gain medium is possible, and this novel technology will become very important in laser engineering field.

Thermo-mechanical issue is very serious in high-power laser generation. Temperature gradient occurs in the laser gain medium at cross-sectional direction due to the heating at the central region and due to the cooling at the outer region of the laser gain medium during high power laser operation. Accordingly, the distribution of refractive index becomes inhomogeneous due to the thermal lensing effect, and the beam quality of the generated laser beam is badly degraded. Moreover, laser power breakdown occurs when input power is supplied to an extent.

Advantage of slab/composite or waveguide type laser is that the cooling from the large surface could be suppressed a thermal gradient inside the core. The above mentioned localized heat generation issues can be neglected, and thermal lens effect and optical anisotropy are remarkably reduced. In contrast, the long direction can use pump beam effectively (high-gain and high-efficiency).

3. **TARGET of RESEARCH**

[Slab/Composite type laser oscillation]

An end-pumping system is used for an oscillation test. Fiber coupled LD (808nm) of the maximum output 375W is prepared for this purpose.

[Sample condition]

Three layer composite (Pure-Nd-Pure) ceramic slab

Size:6 x 6 x 20mm (Length is adjusted by polish processing if needed)

Doping concentration: 0.6at%, 1.0at% (*Doping length is 10mm)

Three layer composite (Gd-Nd-Gd) ceramic slab

Size:6 x 6 x 20mm (Length is adjusted by polish processing if needed)

Doping concentration:0.6at%, 1.0at% (*Doping length is 10mm)

[Performance goal]

Slop efficiency: over 50%, and beam quality: Good

[Adv. Waveguide type laser oscillation]

A side-pumping system is used for an oscillation test. Stacked LDs (808nm) of the maximum output 432W is prepared for this purpose.

[Sample condition]

(1)Advanced waveguide type using composite core layer

Size:1.0 or 1.5 x 10 x 30mm

Core doping concentration:0.6at%

Core thickness:0.4mm, 0.6mm

[Performance goal]

Slop efficiency: over 50%, and beam quality: Good

Budget Summary

Sample Type	Input Power	Pump	Schedule	Budget
Slab/Composite slab	50W		Nov.15	25k
	100W		Nov.15	
Adv. waveguide	50W		Mar.15	-----
	100W		Apr.15	

4. **EXPERIMENTAL RESULTS [Laser oscillation tests of Slab/Composite type]:** Four kinds of three layer composite ceramic slab were prepared in this experiment (Fig.1). All of sample was manufactured by Dr. Ikesue of World Laboratory Co., Ltd. A laser active layer (e.g., 0.6at% or 1.0at% Nd:YAG with 10mm thickness) is arranged at the center, pure YAG or Gd is strongly bonded at the atomic level on both faces of it. Each thickness of pure YAG or Gd is 5mm thickness.



Fig.1 Three layer composite ceramic slabs used in this measurement.

A LD of 808nm was used for a laser oscillation experiment as a pumping laser light. The sample was attached in a copper heat sink by using heat conduction grease. The heat sink cooled off in two thermo-electronic cooler (TEC: 100W). AR coating was coated to two surface of pumping light input and laser output respectively. The sample was put between two flat mirrors and constituted a resonator. The mirror of 20% of transmittance was selected as an output coupler (O. C.). The resonator length was approximately 30mm. A measured input output characteristic is shown in figure 2.

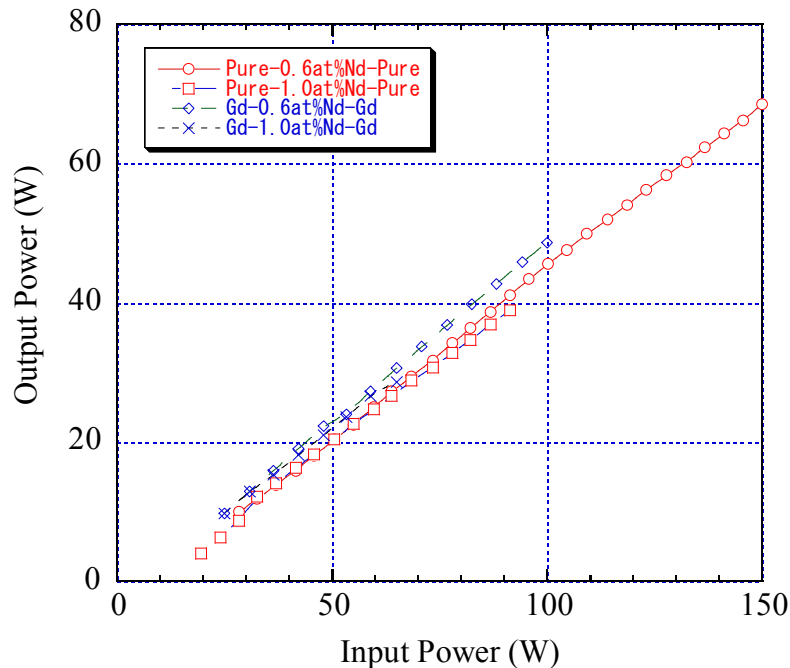
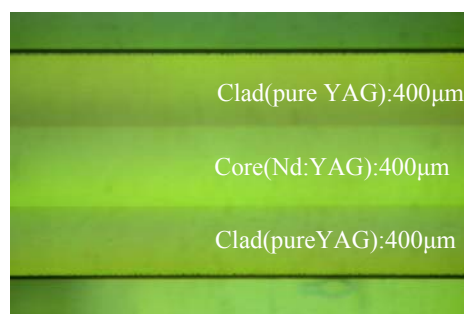
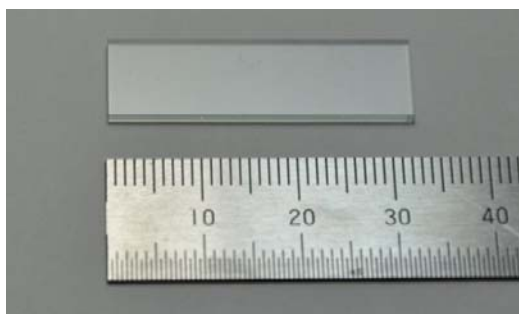


Fig. 2. Figure showing the relationship between input and output power for the three layer composite ceramic slab.

An input power was increased until it was cracked in all samples. In the Pure-0.6at%Nd-Pure sample, laser output of 69W was obtained at input power of 150W. The sample of Nd concentration 0.6at% had higher oscillation output than that of Nd concentration 1.0at%. A thermal impact was thought to be large by high pumping density in the sample of 1.0at%. Gd-0.6 or 1.0at%Nd-Gd structures had a small input power before a crack occurring. However, Gd-0.6 or 1.0at%Nd-Gd structures are more efficient than Pure-0.6 or 1.0at%Nd-Pure, but the cause is not understood from this experiment. 50% of slope efficiency was able to be achieved in all samples. To obtain higher laser output, it is important that heat generation is cooled off from a ceramic sample effectively. For this purpose, the laser medium of the waveguide type is suitable.

[Adv. Waveguide type laser oscillation]

The waveguide sample of the 32mm length was prepared for the evaluations of the side-pumping (Fig. 3a). All of sample was manufactured by Dr. Ikesue of world laboratory Co., Ltd. A laser active layer (e.g., Nd:YAG with 400 μ m thickness) is arranged at the center, and low refractive index materials (high thermal conductive material: pure YAG) is strongly bonded at the atomic level on both faces of it. Each thickness of pure YAG is over 400 μ m thickness. As a result, the thickness of the whole sample becomes 1.2mm (Fig. 3b). From a micro photography, the interfacial condition bonded together is excellent. In the side of the sample (10mm x 1.2mm), gradient processing (3 degree and 4 degree) is taken for ASE prevention. Sapphire was placed outside them more to make pump beam have total internal reflection (TIR). Power density of the pump beam determined the thickness of YAG and the Nd:YAG.



(a)

(b)

Fig.3 (a) Photograph of the sample with 400 μ m thickness core, (b) Micro photography of the bonding boundary surface.

LD of 808nm was used for a laser oscillation experiment as a pumping laser light. Maximum output of the LDs is 432W. The pumping laser light was incident from edge face of 1.2mmx10mm of the sample. A sample of 32mm propagates as parallel beam by collimating to 8mm width with a focusing unit. A vertical focusing condition was adjustable from 400 μ m to 1000 μ m. The sample was attached in a copper heat sink by using heat conduction grease. The heat sink cooled off in two thermo-electronic cooler (TEC: 100W). AR coating was coated for all the edge face of the sample. The sample was put between two flat mirrors and constituted a resonator. The mirror of 20% of transmittance was selected as an output coupler (O. C.). The resonator length was approximately 13mm.

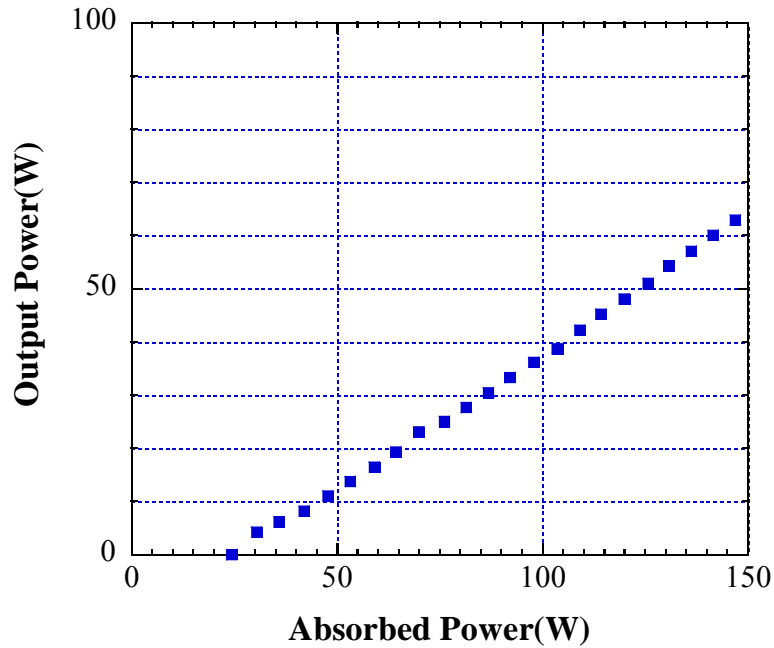


Fig 4: Graph showing the relationship between absorbed power and output power for side-pumping experiment.

Relationship between absorbed power and output power is shown in figure 4. The laser output was taken out from the surface of 1.2mm x 32mm. As absorbed powers increased, the laser output rapidly increased. At the region with 80W or more absorbed power, output power almost increases in linear shape. Absent maximum output 62W was obtained from approximately 150 W of absorbed powers. Over 50% of slope efficiency was achieved. The crack of the sample and thermal saturation of the output power cannot be confirmed in this experiment. The oscillation experiment of higher output is going to be performed in other grant "Basic Research for AOARD 104092 "Evaluation of laser oscillation property in wave guide polycrystalline ceramic., dated 26 Mar10".

5. CONCLUSIONS

The laser characteristics of slab/composite and waveguide ceramic sample developed and provided by Dr. Ikesue of World Laboratory Co., Ltd. were evaluated. Four kinds of three layer composite ceramic slab (Pure-0.6 or 1.0at%Nd-Pure, and Gd-0.6 or 1.0at%Nd-Gd) were prepared for this experiment. At the end-pumping laser oscillation, approximately 50% of slope efficiency was achieved in all samples. In the pure-0.6at%Nd, laser output of 69W was obtained at input power of 150W. However, a sample broke by thermal saturation due the strong pumping density. The laser medium of the waveguide type is suitable for high-power laser oscillation due to its effective cooling property. The waveguide sample of the 32mm length was prepared for the evaluations of the side-pumping. Current maximum output 62W was obtained from approximately 150 W of absorbed powers. Over 50% of slope efficiency was achieved. The crack in the sample and thermal saturation of the output power cannot be confirmed in this experiment. The oscillation experiment of higher output is going to be performed in other grant "Basic Research for AOARD 104092.